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## A method for monitoring reactive strength index

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### Abstract

Ubiquitous motion sensors in shoes and clothing are becoming more prevalent. This new data stream opens a large opportunity to gain a deeper understanding of human movement. This paper describes the development and validation of an algorithm to calculate reactive strength index (RSI) from an accelerometer mounted at the ankle. Compared to the gold standard force-plate, the accelerometer and algorithm RSI had  $r = 0.98$ , mean difference = 0.001 m/sec and a confidence interval ranging from 0.12 to -0.11 m/sec. Difficulty in accurately identifying take-off using the accelerometer was the main source of measurement error.

© 2010 Published by Elsevier Ltd. Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/3.0/).*Keywords:* accelerometer; feature extraction; algorithm development; reactive strength index; validation; force plate; athletic performance

### 1. Introduction

Providing athletes and coaches with fast, accurate and context appropriate measurements of athletic performance is important for improving athletic development and elite performance. Wearable sensor technology is heralding in a new age of data capture which will allow performance metrics to be captured ubiquitously throughout a training session [1]. In this paper we look at the development and validation of a measure useful to explosive sport athletes that can be obtained easily with an accelerometer mounted on the ankle or in the shoe.

Explosive sport athletes must attain very high levels of physical performance to play at an elite level. Not only do they need to produce a lot of force, they also have to do it very quickly. Being deficient in either one of these aspects means that they would be over-powered or left behind by their opponent in a game situation. An athlete's stretch-shortening cycle (SSC) functioning is a vital component of their ability to produce high force in a short amount of time. Fast SSC means that an athlete can make the most of the passive and active components of their muscle-tendon units to move as fast as possible around the court or field [2]. SSC functioning is quantified by the reactive strength index (RSI) as measured from a drop jump [3].

RSI has been used by strength and conditioning professionals for a variety of purposes. McClymont & Hore, 2003 used RSI to optimize plyometric training and prevent injuries [4]. Flanagan & Comyns, 2008 found that RSI was a good motivational tool for their rugby players during plyometric training. They reported RSI values for

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trained athletes around 2.5 m/sec and 1.5 m/sec for untrained athletes [5]. Other research has suggested that RSI could be used as a recovery tool to determine the recovery state of an athlete [6, 7]. RSI is calculated using equation 1 below.

$$\text{Reactive strength index} = \text{jump height (m)} / \text{ground contact time (sec)} \quad (1)$$

The force-plate is the gold standard measure for RSI. In the field RSI is most commonly measured with a contact mat, which is much cheaper and easier to use than a force-plate. We feel it is appropriate to have a method to determine RSI from an accelerometer because it is more ubiquitous than a contact mat; it does not require the user to transport or lay down a mat for measurement. An accelerometer placed around the ankle also has the added potential of being used to calculate many more metrics of athletic performance such as stride characteristics during running.

This paper describes the development and validation of an algorithm to calculate reactive strength index (RSI) from an accelerometer mounted close to the ankle.

## 2. Methods

A validation study was undertaken in which 20 physically active participants volunteered. 6 were female and 14 were male. Their average age was 27.1 yr (+/- 4.55 yr), average weight 79.1 kg (+/- 9.15 kg) and average height 181.7 cm (+/- 6.87 cm). Before they began the study, each subject was told the risks of participation and then they read and signed an informed consent form in accordance with the ethics committee of the university.

An MTx sensor from Xsens (Enschede, Netherlands) was used for data collection. This includes rotation rate and accelerometer data, however just the accelerometer data was used. The sensor range was set to +/- 6 G. Feature extraction algorithms were developed in MATLAB R2008a (Natick, Massachusetts).

Each testing session consisted of 5 drop jumps with an Xsens MTx sensor attached to each foot. The subjects stepped off of a box raised 35cm off of the ground and performed their rebound jump with each foot landing on a separate AMTI force plate (Watertown, Massachusetts) embedded into the floor. The Xsens MTx sensors were sampled at 512hz and the AMTI force plate at 1000hz. Data was synchronized post-collection in software by lining up the first landing in the data on both data sets.

### 2.1 Algorithm Development

To determine an athlete's RSI from force plate or accelerometer data ground contact time and jump height from a drop jump must be determined. Ground contact time can be determined by first finding the initial landing in the data and then finding the subsequent take off. Jump height is determined by first finding air time, which is done by finding take-off and the subsequent landing. Jump height can then be determined from air time based on the equation described in Linthorne, 2001 and shown in equation 2 [8].

$$\text{Jump Height} = \text{Gravity} \times (\text{air time})^2 / 8 \quad (2)$$

This is quite simple with a force-plate, the top portion of figure 1 shows the vertical force profile from a drop jump done on a force plate. Ground contact time and air time are determined by setting thresholds at 10 N and looking for positive going crossings to find the landings and a negative going crossing to find the take-off point [9]. Finding these points from 3-axis accelerometer data from the ankle is not quite as consistently clear because the accelerometer is mounted on the ankle and is always measuring some sort of movement acceleration – even in the air, while the force-plate will record zero once the athlete has left the ground. The bottom graph in figure 1 shows the corresponding accelerometer data.

The desired features in the data are found by converting the x, y and z acceleration signals into one via a root mean square (RMS) calculation, shown in equation 3. The RMS provides a measure of dispersion of the acceleration relative to zero [10].

$$\text{Root mean square} = \text{sqrt}(ax^2 + ay^2 + az^2) \quad (3)$$

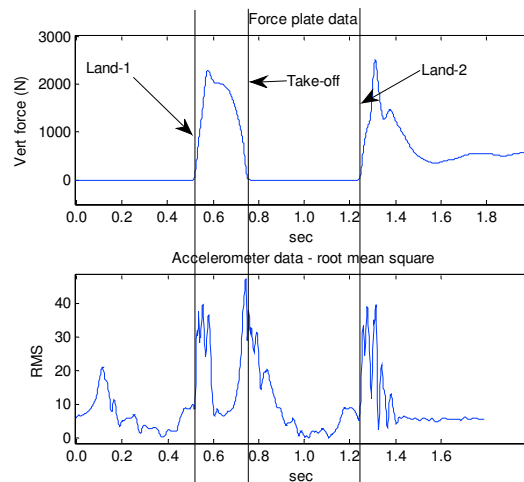


Figure 1 - force plate data and the corresponding accelerometer data from a typical drop jump. The vertical lines show where each landing and take-off occur. It is much easier to search for landings and take-off in the force-plate data than the accelerometer data. This is because the force plate will record nothing once the athlete has left the ground, whereas the accelerometers will still record movement since they are attached to the ankle.

Using the RMS means that the user of the system can mount the accelerometer unit on in any orientation. Trying to line up a sensor with a limb segment may sound simple, but in actual practice with users it can easily lead to erroneous results and frustration with the system. RMS will reflect vertical acceleration the most since in the drop jump the majority of accelerations will be occurring in the vertical plane.

After the RMS of the acceleration signals has been calculated the feature finding algorithm then looks for the three large spikes to determine roughly where each of the landings and the take-off occur. For an algorithm to work on a variety of athletes, it is important not to code hard numerical values into the search. First, this algorithm determined the maximum value in the RMS signal, then set a threshold of 40% of the maximum as a search criteria to look for a spike. This way, the algorithm will work for an elite level rugby player with high acceleration as well as a young female field hockey player who would develop significantly less acceleration.

The landings are then zeroed in on by searching back to the beginning of the large loading spike seen at landing. Sometimes, the athlete will generate high acceleration while they are stepping off the box at the beginning of the drop jump. This high acceleration can sometimes be above the searching threshold for the first landing and can cause landing to be found too early. A check on the linear enveloped jerk curve is sufficient to determine if this has happened. If the jerk value is less than 3 units, then the algorithm searches forward until the jerk value increases over 3 units and this is the new landing point.

Take-off was more difficult to determine than landing due to the fact it was not associated with a very sharp change in acceleration. It was found that athletes with shorter ground contact times tended to have take-off occurring after the peak on a 13 Hz low pass filtered RMS curve, as shown in figure 3. Athletes with longer ground contact times tended to have take-off occurring at the peak on the filtered RMS curve, as shown in figure 4.

Ideally, there would have been some clear characteristics in the data that could signify which take-off finding method would be required. After an in-depth analysis came up with no consistent data feature to differentiate, it was decided to use ground contact time to determine which take-off finding method should be used.

Take-off was found by first finding the peak RMS filtered value after the 40% max value as described previously. However, there are sometimes bumps around the peak, so a check was needed to see if another peak occurred within 0.01 seconds. If it did then that was the new take-off point. If ground contact time at that point was less than 0.25 seconds then take-off was found at the mid-point between the peak on RMS filtered curve and the peak on the absolute differential of RMS, as shown in figure 3. This is similar another study which used double differentiated acceleration to find movement features in accelerometer data [11]. The differential was linear enveloped to allow for easier searching since it had such high frequencies present.

This difference in where take-off occurs between drop jumps with different ground contact times is indicative of different motor patterns between athletes who perform the drop jump with ground contact time less than 0.25

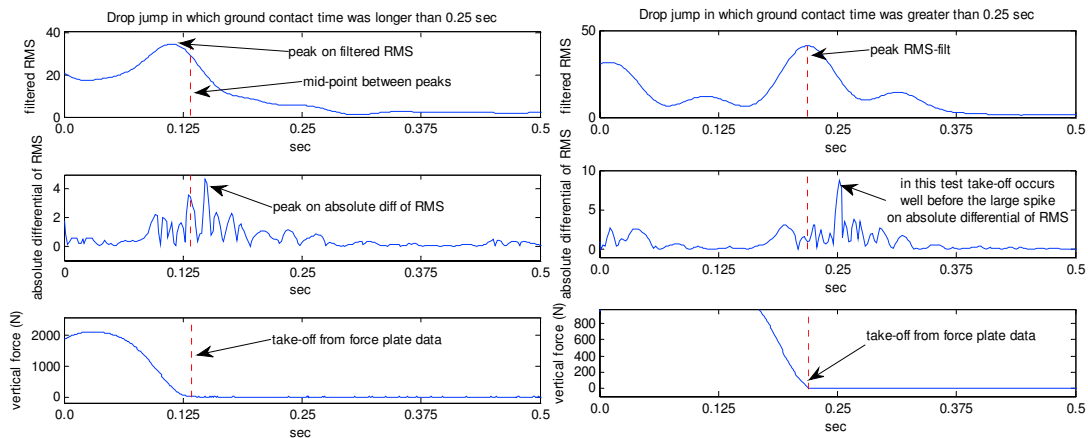


Figure 2 - The left side of the figure shows a test with ground contact less than 0.25 seconds. Take-off occurs at the mid-point between the peak on the filtered RMS curve and the peak on the absolute differential of RMS. Take-off for athlete's with ground contact times longer than 0.25 seconds are generally found at the peak value on the filtered RMS curve, this is shown on the right side of this figure.

seconds and those with longer ground contact times. The longer ground contact time group are not utilizing the passive component of their muscle-tendon units to their full potential.

This 0.25 second threshold is in line with a suggested divide between fast and slow SSC movements for explosive performance training [12]. Determining which type of SSC movement should be trained is dependent on the type of SSC movement that the athlete is required to perform in their sport.

Using the results from our validation data collection provides an opportunity to make the mean difference of the data zero and allows for equal positive and negative confidence intervals. A linear regression equation was developed from plotting RSI from the accelerometer against RSI from the force plate. The regression equation developed from the data was;

$$RSI = 1.103 \times (\text{original RSI}) - 0.160 \quad (4)$$

This regression equation was used in the algorithm to calculate RSI from the ankle mounted accelerometer.

### 3. Results

The validation results obtained compared RSI calculated from the accelerometer and algorithm to RSI from the gold standard force-plate. The Pearson product correlation was 0.9816, the mean difference was 0.001 m/sec and the confidence interval ranged from 0.12 to -0.11 m/sec.

Using a Bland-Altman style validation analysis Figure 9 shows the difference in measures plotted against the mean of both measures on each trial [13]. This graph shows clearly that there is a mean off-set of 0.001 m/sec between both the systems and that 95% of the time the accelerometer will be within 0.12 to -0.11 m/sec to the gold standard force plate measure.

### 4. Discussion

The correlation results are encouraging as they show strong agreement between the accelerometer method and the gold standard. However, the Bland-Altman results, specifically the confidence interval calculations, highlight some potentially important discrepancies between the force-plate and accelerometer RSI values. These must be considered before the accelerometer and algorithm RSI can be considered equal to the gold standard measure.

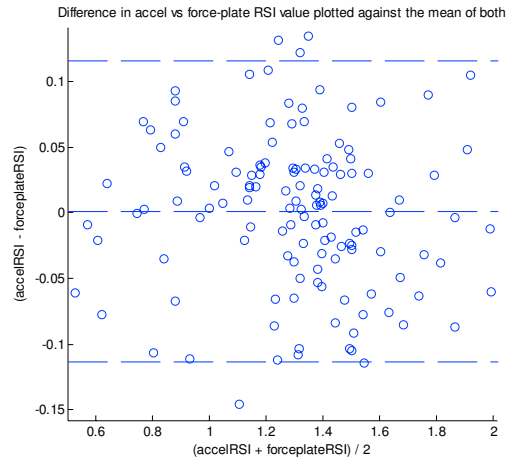


Figure 3 - Bland-Altman style plot comparing the difference between the accelerometer RSI score and the force-plate RSI score. The dashed horizontal lines show the 95% confidence interval.

The confidence interval achieved in this validation should be considered in the context of price and the ubiquity of such a system. A force plate costs €10,000 and has to be run by a trained lab technician. 3-axis accelerometers can be as cheap as €20 and can be used by anybody once the appropriate user interface is created. Small accelerometers can be manufactured into shoes and designed to communicate wirelessly with an athletes' watch or a coach's PDA. A drop jump could then be measured at any point during a workout without the need to lay down a timing mat or use a force-plate.

Knowing the confidence interval of a new measurement tool is vitally important when designing interfaces for users to interact with. An interface to monitor day to day athletic performance which uses the algorithm described here should not indicate to a coach that an athlete has a heightened or lowered RSI if their RSI score is not more than 0.12 m / sec different than their normal score.

A user's degree of satisfaction with this validation would depend where on the athletic continuum their athletes sit. World-class performers, whose performance changes of miniscule amounts mean the difference between winning and losing might deem this confidence interval too large. However, these users likely already have access to such sophisticated equipment as the force-plate. Users on the development end of the spectrum may find that this confidence interval is adequate for their athletes, since performance increases during development are quite large.

The main reason that the confidence interval was not lower was the difficulty in finding take-off accurately. From the collected data-set there was not a consistent feature on any of the acceleration curves or their derivatives which consistently signalled take-off between different subjects. Sabatini et al, 2005 had similar problems with their accelerometer / gyroscope sensor in detecting toe-off during gait with the sensor mounted on the subjects shoe [14]. Take-off is difficult to find because it is not associated with a sharp change in acceleration. It is a soft feature and it is easy to determine roughly where it occurs, but very difficult to zero in on exactly where it occurs with the accuracy required by athletic coaches.

There are four considerations to take into account to when seeking to improve take-off identification. Firstly, the fact that fast-SSC performers and slow-SSC performers had take-off occurring at different points on the acceleration profile suggests that perhaps specific algorithms can be designed for specific groups of athletes resulting in higher levels of accuracy. Secondly, placing the sensor on the foot may allow for more accurate take-off finding since accelerations due to the rapid ankle flexion movement could then be sensed. Thirdly, using gyroscopes may be helpful in finding take-off more accurately since a foot mounted gyro can give data regarding dorsi / plantar flexion rate. Finally, it may be worthwhile to consider other technologies to detect take-off properly, such as current conducting materials in the sole of an athletic shoe which would indicate when the athlete is in contact with the ground.

## 5. Conclusions

It is important to have a method to calculate RSI from an accelerometer on the shoe because having an easy way to measure RSI means that coaches can optimize plyometric training, motivate their athletes during training and monitor fatigue. Such use will eventually result in a deeper understanding of how to design training programs to maximize explosive performance.

Ubiquitous sensor systems are becoming common-place, as evidenced by the popularity of such commercial products as the Nike iPod shoe sensor and the Polar Shoe Pod. This technology will continue to decrease in price and size and become more prevalent in shoes in years to come. Such a sensor could also be used to measure ground contact time, landing forces, jumping power and a variety of other measures that are relevant to sporting performance. It is the hope of the authors that the techniques described in this paper can be useful to others in trying to obtain useful data from accelerometers mounted on the human body.

Future work on this topic should focus on development of a more accurate method to find take-off.

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